Possible Areas of Collaboration in Ion Sources and Cross Section Measurements

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U.S.-Japan HIF Workshop
Princeton, New Jersey
June 12, 2004

Some Possible Topics for Collaboration

Measurements of multi-electron loss cross sections on low-charge state medium and heavy mass ions

Measurements of total-charge-changing cross sections for negative ions and singly-charged positive ions of similar masses

Development of halogen ion sources for positive or negative ions (and fast switching techniques, perhaps bipolar)

Development of high charge state ion sources for moderate cost high energy density physics studies

•Features of Negative Ion Drivers

♋Negative ion beams will not draw electrons from surfaces, so focusing properties will not be contaminated (no electron clouds).

♋Negative halogen beams extracted from ion source do not have the low energy charge exchange tails of positive ions.

♋If eventually want atomic beams, negative ions can be efficiently converted to atomic beams with photodetachment neutralizers.

♋For sufficiently low target chamber pressures, atomic driver beams would reduce average beam self perveance and spot size.

Halogen Ion Source Characteristics Appear Acceptable for HIF

- Current densities adequate for HIF, and similar to positive ions (so extractable currents will be limited by extractor design for either negative or positive ions)

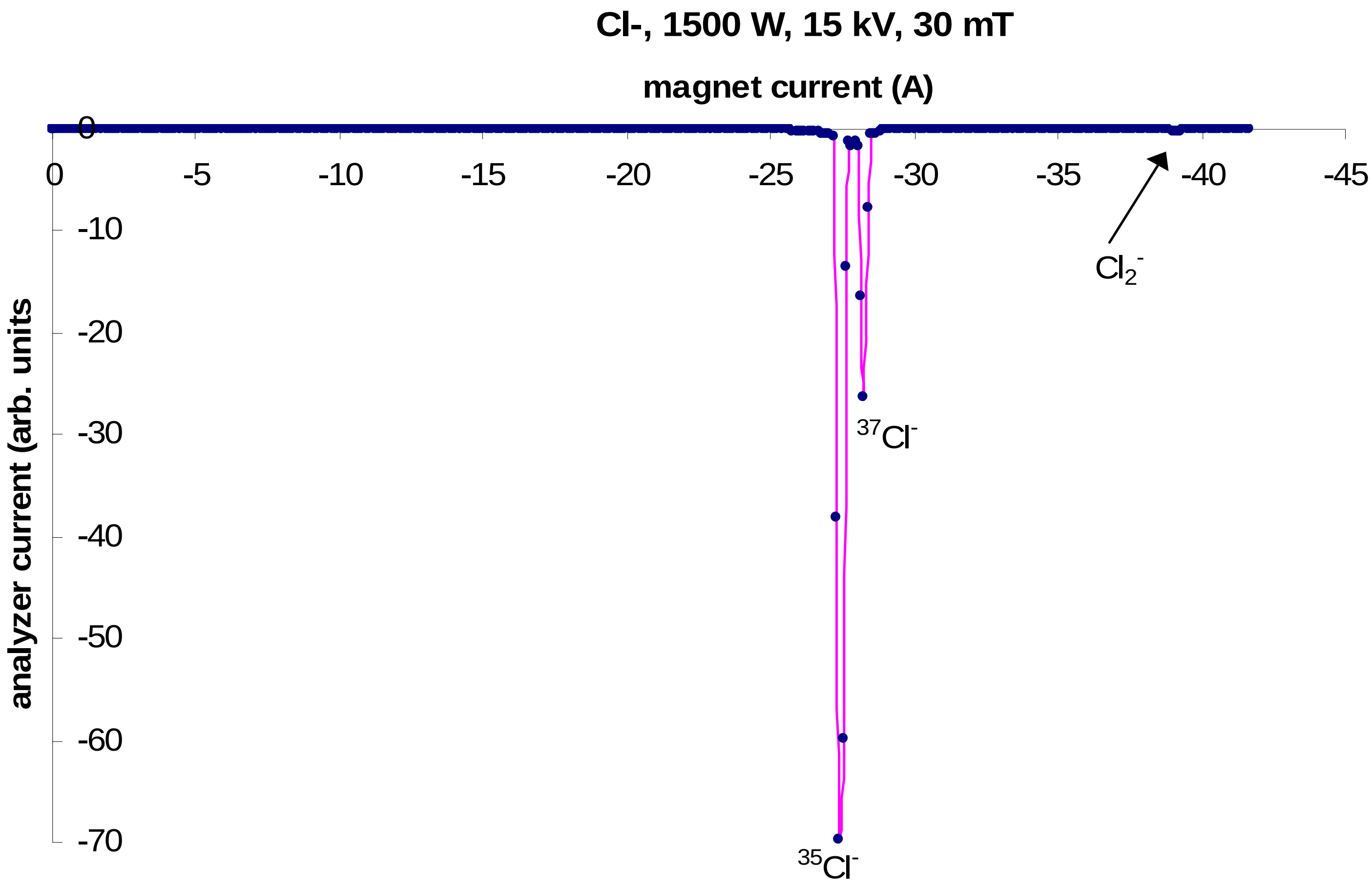
- Negligible negative molecular ions or contaminants

- Negligible charge exchange tails to increase longitudinal emittance

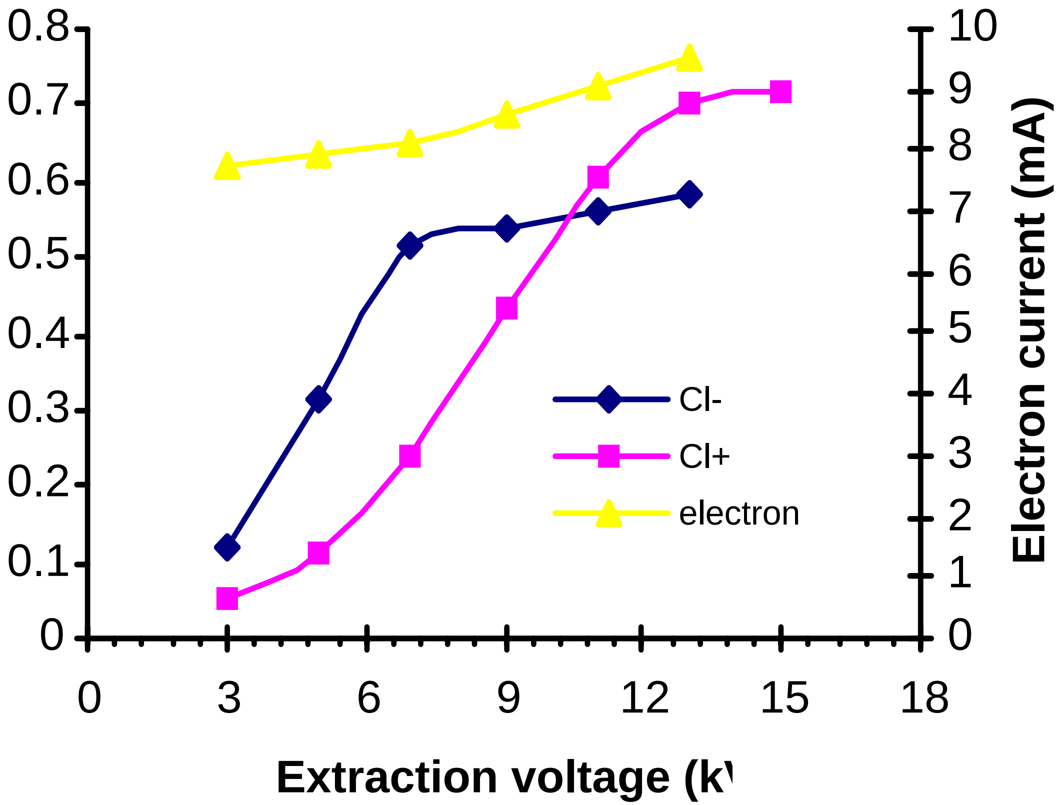
- Ion-ion plasma results in few co-extracted electrons

- Perhaps because of low ambipolar potentials and shorter gradient lengths in ion-ion plasmas, T_{eff} of both negative and positive beams appears low, so halogen sources might allow smaller spot size for both positive and negative ions than would positive ions from ion-electron plasmas.

Negative Chlorine Spectrum is 99.5% Atomic, with Negligible Tails



Chlorine, with Electron Affinity of 3.61 eV, Yields More Negative Ions and Fewer Electrons Than Oxygen with Affinity of 1.46 eV



Halogen Sources Might be Applicable to Recent Japanese Interest in Beams of Alternating Bunches of Positive and Negative Ions

- Halogens permit establishment of ion-ion plasmas with few electrons in extractor plane region.

- It appears from initial results that the T_{eff} of both negative and positive ions extracted from such plasmas may be lower than for positive ions from ion-electron plasmas

- Quite similar current densities of positive and negative ions can be extracted from same discharge by switching extraction polarity

- If suitably fast bipolar switching could be applied, and if the sheath formation time were short enough, might extract alternating charge bunches of the same mass from one source

- If bipolar voltages could be asymmetric, could equalize positive and negative currents.

Critical Technical Issues

♋**Choice of beam element** (Halogens demonstrated successfully)

♋**Ion source**

Would benefit from development of heated Br and I sources, as well as optimization with Cl

♋**Photodetachment neutralizer**

♋**Vacuum requirements in accelerator and beam transport system**

Would benefit from measurements of total charge changing cross sections

♋**Ionization of beam particles in target chamber**

Would benefit form measurements of more multi-electron loss cross sections

Recent One Week Stay at RIKEN Wakoshi

Discussions at RIKEN and Tokyo Institute of Technology about possibility of using RILAC to compare total-charge-changing cross sections of F^- with Ne^+ (limited to A/q not more than 28)

Run ECH source on F at low power, buy new extractor supply, add gas stripper after RILAC, use steering magnet for analysis, add detector on side of magnet housing; need Japanese group to propose if interested and feasible

Also visited JAERI Tokai site following week while at JT-60U

Only accelerator there which could accelerate low charge state ions is the 16 MV tandem. Negative ion source at ground can make all negative halogens, but would require doing experiment in terminal. Appears not feasible.

Difficulties: (1) current stability maybe only 5-10%, (2) gas stripper removed (and no pressure measurement), (3) Faraday cup not well electron-suppressed, and poor accuracy

Scoping Study to Estimate Appeal of a Modest Cost Facility for HEDP Experiments

Requirements:

High power density and high uniformity across thickness of target

Short pulse length so target remains stationary during pulse

Assumed Hardware Configuration (from Grant):

1 Megavolt extractor/accelerator stage

Compression region with additional 1 megavolt acceleration to compress 200 nanosecond pulse to 1 nanosecond (probably needs to be shorter)

Assumed plasma lens focuses the beam to a 1 mm radius uniform spot on target

Optimizing Uniformity and Magnitude of Power Deposition

Charge state equilibrium occurs rapidly in solids (0.3 - 0.5 microns for Ne to reach +7, Kaganovich); for ions heavier than helium, we assume beam of helium-like ions, so they enter the target at or very near equilibrium charge state; consequently energy deposition should be uniform almost immediately.

The dE/dX curve peaks at 8 - 13 x 10^8 for beams from B to Cl, moving slowly higher with atomic number; peak location is only weakly dependent on target.

Because the rate of change of energy loss is smallest near the dE/dX peak, picking a beam energy near, and preferably slightly above the peak, and a target thickness such that the beam exits before leaving the peak, gives the conditions under which both the energy deposited per unit volume and the uniformity through the target are maximized.

Electronic Stopping Power as Function of Velocity
$V_0 = 2.188 \times 10^8$ cm/s

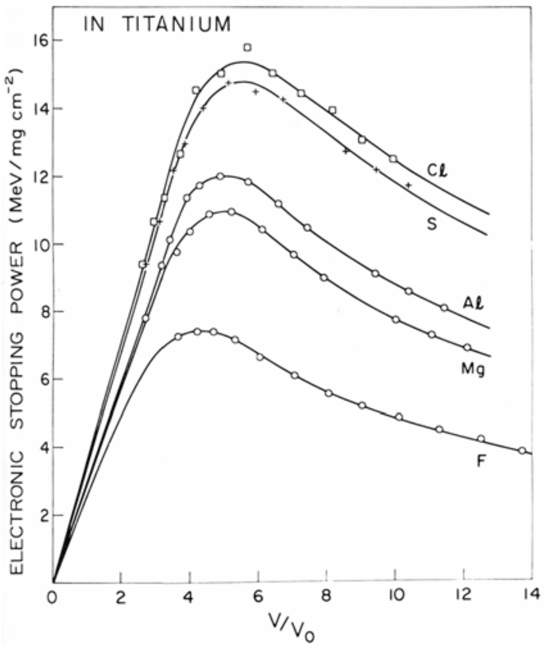


Fig. 3. Experimentally determined electronic stopping powers for F, Mg, Al, S and Cl projectiles in titanium plotted against reduced velocity v/v_0, where $v_0 = e^2/h \approx 2.188 \times 10^8$ cm/s. The solid curves were drawn by eye to assist interpolation and have been extrapolated by the procedures discussed in the text.

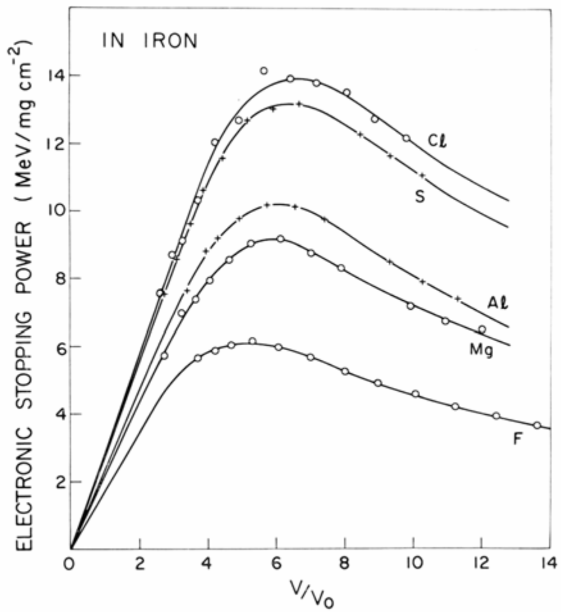


Fig. 4. Experimentally determined electronic stopping powers for F, Mg, Al, S and Cl projectiles in iron plotted against reduced velocity v/v_0 (see fig. 3).

Velocity of dE/dX Peak Climbs Slowly with Beam Z

Deposition Characteristics for Sample Beams in 1 Micron Target

Beam Ion	E_b(MeV)	Range (microns)	Energy Dep (J/m^3)	Uniformity %Min-Max dE/dx	dE/dX Peak (MeV)	Accelerated Power (MW
H^+	1	11.4	3.9×10^{10}	3	0.112	11
H^+	2	31.2	2.5×10^{10}	1.6	0.112	22
He^+	1	3.1	1.5×10^{11}	4	0.72	5.5
He^+	2	5.7	1.2×10^{11}	6.5	0.72	11
N^{+5}	10	5.8	2.7×10^{10}	0.7	7.7	2
Ne^{+8}	16	6.3	4.4×10^{10}	0.3	15	3.2
Ne^{+8}	8	3.9	3.9×10^{10}	13	15	1.6
Ar^{+16}	32	7.6	8.0×10^{10}	5	57	6.4
Kr^{+34}	68	9.5	1.5×10^{11}	7	177	13.6
Xe^{+52}	104	10.8	2.1×10^{11}	8.5	375	20.8

Short Hydrodynamic Times for 1 Micron Targets Require either More Compression of Beam Pulses or Thicker Targets (or both)

Beam Ion	Energy (MeV)	T_e (K)	V_{hydro} (m/s)	$T_{transit}$ (10^{-9} sec)
H^+	1	8.3×10^3	1.7×10^3	0.59
H^+	2	5.3×10^3	1.4×10^3	0.74
He^+	1	3.2×10^4	3.3×10^3	0.30
He^+	2	2.6×10^4	3×10^3	0.34
N^+	10	5.8×10^3	1.4×10^3	
Ne^{+8}	16	9.4×10^3	1.8×10^3	0.55
Ne^{+8}	8	8.3×10^3	1.7×10^3	0.59
Ar^{+16}	32	1.7×10^4	2.4×10^3	0.41
Kr^{+34}	68	3.2×10^4	3.3×10^3	0.30
Xe^{+52}	104	4.5×10^4	3.9×10^3	0.25

Reasonable Uniformity Can Be Achieved with Thicker Targets (Especially if Acceleration Capability is Modestly Increased)

Beam Ion	Energy (MeV)	V_{acc} (MV)	Ti Target thickness (microns)	Deposited Energy (J/m^3)	Uniformity (%) Min-Max dE/dx
He^{+}	1.6	1.6	3	1.4×10^{11}	15
Ne^{+8}	16	2	3	4.1×10^{10}	11
Ne^{+8}	20	2.5	3	4.3×10^{10}	3
Ne^{+8}	25	3.125	5	4.3×10^{10}	7
Kr^{+34}	269	7.91	10	1.8×10^{11}	4

Developing High Charge State Ion Sources for Short Pulses Would Improve Prospects for Modest Cost HIF HEDP Facility

- Grant Logan has suggested using ECH sources with time-of-flight selection of desired charge state

- The higher the charge state, the lower the acceleration energy could be to access the dE/dX peak with a heavy ion, and the lower the cost of the HEDP facility

- Ideally, would like helium-like ions of noble gases